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EUROPEAN ATOMIC ENERGY COMMUNITY - EURATOM

A TIME-OF-FLIGHT ANLYZER BASED ON A SMALL ON-LINE COMPUTER

by

H.J. METZDORF

1968

Joint Nuclear Research Center
Ispra Establishment - Italy

Reactor Physics Department
Experimental Neutron Physiscs

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SUMMARY

A program is described for a small on-line computer used as a time-of-flight analyzer. The structure of its pseudo-code is explained and the details of a sample run are given.

KEYWORDS

TIME-OF-FLIGHT SPECTROMETERS
ON-LINE COMPUTERS
PROGRAMMING

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A TIME-OF-FLIGHT ANALYZER BASED ON A SMALL ON-LINE COMPUTER(o)

Introduction

Experimental arrangements for time-of-flight (TOF) measurements can benefit from the inherent flexibility of fast on-line computers. The great strength of computer oriented TOF facilities is that very special experimental requirements can be dealt with by simple program modifications. Examples of such flexibility are:

1. different channel numbers can be assigned to different detectors for optimizing the information gain within the limitations of available storage capacity,
2. the spectrum display can be tailored to the convenience of the experimenter,
3. the format of data output can be adapted to the input requirements of other computers used for further data processing,
4. small scale data handling can be performed by the on-line machine itself between spectrum recordings, and
5. contrary to specialized analyzers, the on-line computer can be switched to a completely different job when the TOF experiment is ended.

The TOF-analyzer for which this program was written is in use with a double chopper facility installed at the ISPRA-I reactor.[*] It consists of

1. a PDP-8 on-line computer[**] with a 4K memory, the automatic restart option, and a display unit,
2. a TOF-converter,
3. conventional counting electronics.

The counting electronics are not unusual, and therefore will not be described here. The TOF-converter provides the computer with digital information about the time a neutron takes to travel from the scattering sample to a detector (up to 12 detectors can be accommodated) and which detector was involved.

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[*] Joint Nuclear Research Center, EURATOM, Ispra, Italy

[**] Manufacturer "Digital Equipment Corporation", Maynard, Mass.

(o) Manuscript received on March 28, 1968.

It operates as follows.
A magnetic pick-up mounted on the chopper sends a pulse to the converter at the moment when a neutron burst starts travelling down the flight path. This pulse is used to start a clock filling a counting register. When a neutron arrives at a certain detector the momentary state of the counting register is copied into a buffer and a program-interrupt-request is sent to the computer to start a subroutine for information handling. The counting register keeps running and can again be copied into the buffer by another neutron signal from the same burst, as soon as a reset has been received from the computer. To provide different channel widths, the interval between successive clock pulses can be varied from 1 to 64 μs. A zero time shift produced by a digitally controlled delay enables the analyzer to record only part of the spectrum on the full number of channels available.
A maximum of 3072 channels with a capacity of 4096 counts/channel is available for spectrum recording. By means of a switch it is possible to select modes to monitor 12, 6, 3 or 1 detectors with 256, 512, 1024 or 3072 channels respectively. The buffer, which is a 12 bit register, receives the information in coded form. For 12 detectors the four most significant digits represent the detector number and the remaining eight digits the time or channel information. For six detectors the three most significant digits give the detector number, and so on. A detailed technical description of the converter can be found elsewhere [1].

Explanations of the instruction code and the symbolic machine language for the PDP-8 are given in the "Small Computer Handbook" *.

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* published by Digital Equipment Corporation, Maynard 1967

Purpose of the program

The main purpose of this program is to enable the computer to interact with the TOF-converter. When the TOF-converter presents a digital time-of-flight datum and the number of the triggered detector to the PDP-8 by requesting a program-interrupt, the computer activates a subroutine enabling it to absorb the TOF information. If the information is valid, the memory location which is assigned to this particular detector-time combination must be incremented by one. If the information is invalid (impossible detector number), it has to be rejected to protect the program. If the incrementation results in an overflow, a message must be given to indicate the number of the channel and the detector involved. The remaining part of the program, which occupies most of the storage locations provided for programming, is responsible for the input and execution of commands. These commands correspond to the various controls which can be found on fixed-wired TOF-analyzers. They are transmitted to the computer via a Teletype keyboard. There are commands for different kinds of spectrum display on an oscilloscope, different modes of spectrum output on punched paper tape or typewriter and a command for reloading of previously punched spectrum tapes. A detailed decription of all commands is given on page 8. Moreover, the program has to do some housekeeping. For instance, it has to keep permanent watch on the automatic restart unit, which raises a flag when the line voltage goes below a certain safety level. When this happens the program has to transfer the contents of all relevant flip-flop registers into the core-memory and stop computation. When the line voltage returns above the safety level the flip-flop registers must be reset to their previous values and the computation resumed.

Operation Commands

When the program has first been loaded the computer is set to handle the case of 12 detectors. If another detector configura-

tion is desired, the content of storage location 0174_8* must be changed from 0014_8 (= 12_{10}) to 0006, 0003 or 0001 respectively. The rotary switch on the converter has to be set correspondingly . The relationship between the addresses of storage locations can be seen in table 1. The starting address for the program is 0200_8. Upon being started, the computer responds with Teletype bell, carriage return (CR) and line feed (LF) and is ready to receive commands via the Teletype keyboard. There are ten basic commands with certain variations which will be described below. To indicate the non-printing characters "CR" and "space" the symbols) and ␣ respectively will be used.

N) Disable data taking. The computer responds with LF. The computer continues on that part of program in progress before the N-command is given (normally this is the display program). When the program is first loaded, data taking should be disabled by N or Z-command because data taking is originally enabled.

X) Enable data taking. The computer responds with LF. The computer continues on that part of program in progress before the X-command is given.

Z) Clear all storage locations provided for spectrum recording. The computer responds with CR and LF. Data taking is disabled. The computer continues on that part of program in progress before the Z-command is given.

Z␣xx) Clear the storage locations assigned to the detector with number xx. The computer responds with CR and LF. Data taking is disabled. The computer continues on that part of program in progress before the Z-command is given. It should be noted, that the actual number of storage lo-

---

*subscript 8 indicates that the number is given in octal form

cations cleared by this command depends on the number stored in location 0174_8.

D) Display the contents of all memory locations provided for spectrum recording. The computer responds with LF. Markers are displayed at the position of lowest and highest channels. Markers are vertical lines extending over the full screen heigth. Since only 1024 different data points are available along the display abscissa, only every third channel can be shown. Interval markers are displayed along the abscissa (see Fig. 1). The display sensitivity is set to the lowest possible value of 4096 counts/full screen height. The interrupt is turned on and if data taking has been enabled data are accepted and recorded in the proper channel. If an overflow occurs in a certain channel a message is punched and/or printed on the Teletype: "xxxx xx FULL", where the first four characters give the channel and the next two the detector number. During this print-out data taking is disabled. The channel is then set to zero and data taking is reenabled. The display continues. Data taking can be stopped with an N-command without interrupting the display. The display will not be completely flicker-free, however, especially when there is a high rate of data input, but this does not present any difficulties because the display is made with a storage oscilloscope.

D␣xx) Display the content of the memory locations assigned to detector xx (xx is a two-character decimal number. To give a one digit number like 2, one has to type 02). This assignment depends on the number stored in memory location 0174_8. Markers are shown at lowest and highest channel positions. If the number of channels to be displayed is greater than 1024, channels are skipped as explained above. Sensitivity

setting, enabling, disabling of data taking and overflow handling are done as for the D)-command.

D␣xx␣xxxx) The same is done as for the D xx command except that the position of the lower marker is specified by the given four-digit decimal number. The upper marker is at the highest channel position. Note that the number of the lowest channel is zero in every group.

D␣xx␣xxxx␣xxxx) The same is done as for the D xx xxxx command except that the position of the upper marker is specified by the second four-digit decimal number.

D␣xx␣xxxx␣xxxx␣xx) The same is done as for the D xx xxxx xxxx command except that in addition the content of a second detector specified by the last two-digit decimal number is displayed. The sensitivity of the display for the second character is set to the lowest possible value of 4096 counts/full screen height.

E) Expands the area of display between the markers over the maximum possible screen width. If this area contains less than 1024 points, all channels will be displayed. This is also the case if the original, non-expanded display was done in skip mode (see D-command). The E-command does not change the state of data taking. If the command for display of two spectra was given before, both spectra will be displayed in the expanded mode. The sensitivity settings are not changed.

Lx Changes the sensitivity of display for the detector whose number was typed on the left hand side of the lower marker position in the preceding D-command. The sensitivity is changed to "lowest sensitivity times 2^x", where x is a decimal digit. The computer responds with a space-character. The computer continues on that part of program in progress before the last interrupt occured. Use of a CR as command terminator was avoided in this case to save paper. A following D-command will override this sensitivity setting and will set it back to the lowest possible value.

Ux Changes the sensitivity of display for the detector whose number was typed on the right hand side of the upper marker position in the preceding D-command. The other specifications are the same as for the Lx-command.

W) Prints the contents of all memory locations between and including the markers in decimal form. A D-command must precede to define the position of the markers. The computer responds with LF. The printed lines contain in their left-hand column the channel number, and in the ten columns on right the number of counts in that and the nine succeeding channels. This command disables the data taking. The display continues.

P) Punches the contents of all memory locations between and including the markers in BIN-format (see Small Computer Handbook). A D-command must precede to define the position of the markers. The computer responds with LF. This command disables data taking. The display continues. Tapes punched by this command can be reloaded into the memory by means of the M-command (see below) or by means of the BIN-loader. Because the BIN-loader occupies the storage locations from 7612_8 to 7755_8 (which is in the block provided for spectrum recording) not all channels can be loaded in this way.

M) Loads a binary spectrum tape in additive mode. The computer responds with LF. The tape must be put on the read station and the reader must be started. The spectrum from the tape is read-in and added to the spectrum already in the memory. If the spectrum on the tape has only to be transfered into the memory a Z-command must precede. When the tape is read-in, the computer halts. One then has to switch off the reader and press the "CONTINUE" key on the computer. The program then waits for the next command. The M-command disables the data taking. During its execution the display does not continue. If a measurement requires all data channels, the RIM and BIN-loaders, which normally occupy the last memory locations, are lost. To avoid the manual procedure to load RIM via the computer switch board a small tape is provided called "TOF binary loader", which can be loaded by means of a Z-M-command combination. It restores both loading routines RIM and BIN.

Description of the program

This program results from a major modification of the DEC program "One Dimensional Display and Analysis". It was written in the symbolic machine language and assembled with MACRO-8. The program listing, which is given in the appendix, is an assembler generated print-out established during the third pass. The first column gives the number of the storage location and the second its content. Both numbers are given in octal form. They represent the result of the compilation. The third column gives a symbolic address (which is optional), separated by comma from a datum or an instruction in the fourth column. In a last column an optional comment is given, separated from column four by a slash. These comments are ignored by the assembler.

When the program is started at location 0200_8 the computer responds with Teletype bell, CR and LF using the subroutine PRINT1. Transfer is made to the READRT subroutine, where the

computer waits for a command to be typed. If this command is given, it is decoded and transfer is made to the program which executes that particular job. If a character is typed, which does not correspond to one of the ten basic commands, it is rejected and the program goes back to wait for another command.

If, during the execution of a basic command, an ION instruction is encountered, the program interrupt will be enabled. In this case the computer is ready to answer program interrupt requests. The interrupt handling routine is stored on memory page 5. There are several sources of program interrupt signals, which are dealt with according to a certain hierachy of priorities. The highest priority is assigned to the automatic restart unit, which requests a program interrupt in the case of mains failure. The program acknowledges the interrupt, stores the content of accumulator, link and program counter in the core memory and waits for power restoration. Then it resumes computation where it was interrupted.

The state of data taking is controlled by the content of storage location INTER. When data taking is enabled it contains the instruction JMP OTHER1, otherwise JMP TTINTR. In the first case TOF interrupts will be acknowledged, in the second one they will be rejected. Before a TOF datum is read-in, the content of accumulator and link are stored, then the information is transfered into the computer, the storage location of the involved channel is calculated and a test performed to check if the TOF-datum is valid. The channel is incremented and tested for overflow. If this is the case, transfer is made to a special part of the program.

The following two subroutines are also stored on memory page 5.

PRINT1, The content of accumulator bits 4 to 11 is printed (and punched) on Teletype according to the ASCII code.

PRNTIR, The same function as PRINT1 is performed with the following exemptions:

1. Data taking must be disabled.
2. During the very slow mechanical print operation the program branches to that part of program which was in progress as the previous program interrupt was acknowledged. Normally this will be the display routine. When the print operation is ended, program is called back to the PRNTIR subroutine. This feature is used in P and W-commands to keep the display running during data output.

On memory page 6 there is location BEGIN (0200_8) where the program must be started. Following the location CMMAND, ten basic commands are decoded and transfer is made to the proper subprogram.

WRITE, After data taking has been disabled the content of all channels between the markers is printed out in decimal form using the PRNTIR routine. The display keeps running. A D-command must precede to define the marker positions. LOMARK and HIMARK are the memory addresses of the channels which correspond to the marker positions. LSTORE is the address of channel zero. The form of the print-out has already been described.

ENABLE, Data taking is enabled by transfering the instruction JMP OTHER1 to INTER.

DSABLE, Data taking is disabled by transfering the instruction JMP TTINTR to INTER.

Memory page 7:

RE1, This short program is used as terminator for subprograms which pass control back to the display routine as WRITE does.

OVRFLO, If a channel gets an overflow as result of an incrementation the channel and detector-number involved

are calculated using the information from DETRNR. Detector and channel-number are printed in decimal form (CASEX) followed by the text "FULL)LF" (PRFULL).

INPUT4, A four-digit decimal number is read via Teletype keyboard and converted to a binary integer.

INPUT2, A two-digit decimal number is read via Teletype keyboard and converted to a binary integer. This program modifies temporarily a parameter in INPUT4 and uses that routine.

READRT, A character is read via Teletype keyboard and its binary equivalent stored in HOLD1. If the character read is a rubout, the program passes control back to BEGIN after having restored instruction at INPUT4+1 to its original form.

Memory page 8:

CLDATA, Data taking is disabled. If the character read after the Z-command was given is different from CR, two additional characters are requested from the keyboard. This information is used to calculate the range of storage locations, which are thereafter zeroed.

SHIFTL, A number is shifted to the left. The number to be shifted must be in SHFTRG. The number of required left-shifts has to be given in the accumulator (a negative number means right-shift, zero means no shift at all). The result is generated in SHFTRG. The accumulator contains zero.

PNTDEC, A binary integer from location LOW is converted and printed as a four-digit decimal number. It uses the PRNTIR subroutine.

EXPAND, The contents of LOMARK and HIMARK are tranfered to locations WLMARK and WHMARK, which represent the values for the screen boundary channels respectively.

Program goes back to the display routine. Therefore the channels between the markers are displayed over the maximum range on the screen compatible with the number of data points along the abscissa.

Memory page 9

WMARK, From the contents of DETRNR and PRODCT the memory addresses of first and last channels corresponding to a selected detector are calculated. PRODCT contains the binary equivalent of a detector number given with a basic command. The result will be stored in WLMARK and WHMARK.

PUNCH, The contents of all channels between and including the position of the markers are punched in binary form. The memory addresses of highest and lowest channels are HIMARK and LOMARK respectively. Some length of leader-trailer-code precedes and follows the data on tape. The loading conventions followed with PDP-8 programs are applied, so that the tape could be loaded with the BIN-loader.

SCALE, The subroutine produces the scale marker attached to the abscissa on display.

MARK, The subroutine produces a marker on the display. Markers are vertical lines displayed over the full screen height.

Memory pages 10 and 11

DSPLAY, This subprogram, which occupies page 10 and 11 controls the display. It consists of three parts.

1. Decode display specifications. The additional information which can optionally be typed following a D-command is decoded. The range of storage locations corresponding to the selected de-

tector is calculated (WLMARK, WHMARK). If no additional specifications have been given, LOMARK and HIMARK are set to 2000_8 and 7777_8 respectively. If marker specifications have been typed, these are used to calculate LOMARK and HIMARK according to

low marker specification + (WLMARK)*⇒LOMARK

high marker specification +(WLMARK) ⇒HIMARK.

If a second detector is selected, the location for its channel number zero (XLMARK) is determined and the display program is prepared for multiple display.

2. Calculate screen markers. All channels from location WLMARK to location WHMARK are displayed on the screen, if (WHMARK)-(WLMARK) ⇒WHL does not excede 1024 (maximum possible data points along abscissa). To use as much space as possible on the screen for the display of the spectrum (especially important for the expand mode of display), (WHL) is successively multiplied by two. If the result exceeds 1024, the process is terminated. The number of multiplications is used to calculate the screen markers:

   SLMARK: Abscissa on screen for the lowest channel to be displayed

   SHMARK: Abscissa on screen for the highest channel to be displayed

   SLOMRK: Abscissa on screen for low marker

   SHIMRK: Abscissa on screen for high marker

   SINC : Abscissa increment for consecutive data points on the screen.

---

*) Brackets indicate content of storage location named.

If (WHL) exeeds 1024 not all channels can be displayed. In this case another constant is calculated:

MINC: Memory location increment for consecutive data points to be displayed on screen.

3. Do the display (INDSPL). The computer will cycle through this program to keep the display alive. Going from left to right, for every abscissa value from (SLMARK) to (SHMARK) the following items are displayed:
Point on the abscissa
Scale marker, if required,
Marker (vertical line), if required,
One or two data points, if required.

Memory page 12

BINPCH, This subroutine punches the content of the accumulator in the form of two successive characters on tape. A checksum is updated.

CHECK, The subroutine accumulates a checksum in LOW.

LEADIN, Some length of leader-trailer-code (200) is punched on tape.

LOWER, It changes the sensitivity of display for the detector specified on the left-hand-side of the marker specification in a preceding D-command.

UPPER, It changes the sensitivity of display for the detector specified on the right-hand-side of the marker specification in a preceding D-command. If this detector was not specified, nothing happens.

LOAD, This subprogram reads a binary spectrum tape previously generated by a P-command. The spectrum is added to the contents of the involved storage

locations. If an overflow occurs, the memory location is set to 7777_8.

BINRD, The subroutine reads a binary character (from tape) into HOLD1.

Program loading

1. Switch on PDP-8
2. Switch on Teletype for on-line operation
3. Place RIM loader into memory as follows:
3.1. Set 7756* in the switch register (SR)
3.2. Press "Load Address"
3.3. Set the first instruction (6032) in the SR
3.4. Press "Deposit"
3.5. Set the next instruction (6031) in the SR
3.6. Press "Deposit"
3.7. Repeat 3.5 and 3.6 until all instructions have been deposited. The RIM instructions are:

address	content
7756	6032
7757	6031
7760	5357
7761	6036
7762	7106
7763	7006
7764	7510
7765	5357
7766	7006
7767	6031
7770	5367
7771	6034
7772	7420
7773	3776
7774	3376
7775	5356
7776	0000
7777	5000

*) instructions and storage locations are given in octal

4. Place BIN loader into memory as follows
4.1. Put the BIN loader tape on the reader
4.2. Set starting address 7756 in SR
4.3. Press "Load Address"
4.4. Press "Start"
4.5. Start the reader
4.6. If the trailer code passes the reader, stop it (on reader and computer)
5. Load time-of-flight (TOF) program as follows
5.1. Put the TOF tape in the reader
5.2. Set starting address 7777 in SR
5.3. Press "Load Address" and
5.4. Press "Start" and start the reader
5.5. When the reader stops, check if accumulator (AC) contains zero. If yes, continue; if not, reading error has occured. Return to 5.1.
6. Prepare display unit
6.1. Switch on oscilloscope
6.2. Set "Vertical Sensitivity" to 1 volt/cm
6.3. Set "Horizontal Sensitivity" to 1 volt/cm
6.4. Set "Horizontal Display" to "Horizontal Amp.Only"
6.5. Set vertical and horizontal input switches to DC
6.6. Set position controls to approximately 12 o-clock
7. Switch on power supply for TOF converter
8. Set starting address 0200 in SR*
9. Press "Load Address"
10. Press "Start"
11. Give command D 01 and observe oscilloscope
12. Adjust sensitivity verniers (red knobs), focus and intensity to suit
13. Give keyboard commands as required

---

* It is assumed that DETRNR which is stored at 0171 already has its correct value; if not, it should be corrected before step 8.

Sample run

The slow chopper facility at the reactor ISPRA-I has been used with a scattering sample of $Ca(OH)_2$. One detector and 256 channels were used (14_8⇒DETRNR). The settings on the converter were: Delay = 0; Interval width = 32 /us.
After several hours of data accumulation the keyboard commands

N

D 01 0025 0080

L3

were given and the first picture was taken (see Fig.1). After an E-command the second picture was taken (see Fig.2). To get a print-out of all channels another D-command was given: D 01 followed by a W-command. The resulting list is given in table 2.

Reference

1) G.Colombo, N.Coppo, L.Stanchi, Nucl.Instr.Meth. 59 (1968) 86

APPENDIX

```
                /TIME OF FLIGHT PROGRAM
                *Ø
0000  0000              Ø
0001  6102              SPL                     /IS IT LOW POWER?
0002  5014  INTER,      JMP OTHER1              /NO
0003  5031              JMP LOWPWR              /YES-HANDLE IT
0004  0000  SAVEAC,     Ø
0005  0000  SAVEL,      Ø
0006  0000  PC,         Ø
0007  0000  AC,         Ø
0010  0000  LINK,       Ø
0011  0000  INDEX1,     Ø                       /INDEX REGISTERS
0012  0000  INDEX2,     Ø
0013  0000  INDEX3,     Ø
0014  6401  OTHER1,     TFS                     /IS IT TOF?
0015  5047              JMP OTHER2              /NO
0016  3004              DCA SAVEAC              /YES
0017  7010              RAR
0020  3005              DCA SAVEL               /SAVE LINK
0021  6406              TFL                     /READ TOF RESET TOF FLAG
0022  1120              TAD P2THOU              /ADD ADDRESS OF REGION
0023  7430              SZL                     /ILLIGAL CHANNEL?
0024  5053              JMP CONTIN              /YES-REJECT
0025  3130              DCA HOLD2               /INCREMENT CONTENT
0026  2530              ISZ I HOLD2             /OF PROPER CHANNEL
0027  5053              JMP CONTIN              /CONTINUE
0030  5777              JMP OVRFLO              /CHANNEL OVERFLOW
0031  3007  LOWPWR,     DCA AC                  /SAVE AC
0032  7010              RAR.
0033  3010              DCA LINK                /SAVE LINK
0034  1000              TAD Ø000
0035  3006              DCA PC                  /SAVE PC
0036  1041              TAD RESTRT              /GET RESTART LOCATION
0037  3000              DCA Ø000                /DEPOSIT IN Ø
0040  7402              HLT
0041  5042  RESTRT,     JMP RESUME
0042  1010  RESUME,     TAD LINK                /GET LINK
0043  7104              CLL RAL                 /RESTORE LINK
0044  1007              TAD AC                  /GET AC
0045  6001              ION                     /ENABLE PI
0046  5406              JMP I PC                /RETURN TO IR.PROGRAM
0047  6042  OTHER2,     TCF                     /IGNORE TELEPRINTER
0050  6031              KSF                     /IF IN INPUT MODE
0051  5057              JMP CONTIN+4
0052  5776              JMP CMMAND              /KEYBOARD
0053  7200  CONTIN,     CLA
0054  1005              TAD SAVEL               /GET LINK
0055  7104              CLL RAL                 /RESTORE LINK
0056  1004              TAD SAVEAC              /RESTORE AC
0057  6001              ION                     /ENABLE PI
0060  5400              JMP I INTER-2           /EXIT
0061  0000  PRINT1,     0000                    /PRINT SUBROUTINE
0062  6046              TLS                     /WITHOUT INTERRUPT
```

```
0063  6041            TSF
0064  5063            JMP .-1
0065  6042            TCF
0066  7200            CLA
0067  5461            JMP I PRINT1
0070  0000  PRNTIR,    0000                /PRINT SUBROUTINE
0071  6046            TLS                 /WITH INTERRUPT
0072  7200            CLA
0073  5054            JMP CONTIN+1
0074  6404  TTINTR,    TFC                 /CLEAR FLAG OF TOF
0075  3004            DCA SAVEAC          /SAVE AC
0076  7010            RAR
0077  3005            DCA SAVEL           /SAVE LINK
0100  6041            TSF
0101  5104            JMP OTHER3
0102  6042            TCF
0103  5470            JMP I PRNTIR
0104  6031  OTHER3,    KSF
0105  5053            JMP CONTIN
0106  5776            JMP CMMAND
0107  7760  MIN20,     7760
0110  0240  SPACE,     0240
0111  0212  LNFEED,    0212
0112  0215  CARRTN,    0215
0113  0277  QMARK,     0277
0114  7563  MINCR,     7563
0115  7401  MRBOUT,    7401
0116  6000  M2THOU,    6000
0117  1000  P1THOU,    1000
0120  2000  P2THOU,    2000
0121  7774  MINUS4,    7774
0122  0400  P4HUN,     0400
0123  7777  MINUS1,    7777
0124  7776  MINUS2,    7776
0125  5777  MSIZE,     5777
0126  0017  MASK15,    0017
0127  0000  HOLD1,     0000
0130  0000  HOLD2,     0000
0131  0000  HOLD3,     0000
0132  0000  HIGH,      0000
0133  0000  LOW,       0000
0134  0000  COUNT1,    0000
0135  0000  COUNT2,    0000
0136  0000  COUNT3,    0000
0137  0000  COUNT4,    0000
0140  0000  COUNT5,    0000
0141  0000  COUNT6,    0000
0142  0000  COUNT7,    0000
0143  0000  COUNT8,    0000
0144  0000  CONST6,    0000
0145  0000  CONST7,    0000
0146  0000  CONST8,    0000
```

```
0147  0000  PRODCT,   0000
0150  0000  LSTORE,   0000
0151  0000  WLMARK,   0000
0152  0000  LOMARK,   0000
0153  0000  HIMARK,   0000
0154  0000  WHMARK,   0000
0155  0000  SLMARK,   0000
0156  0000  SLOMRK,   0000
0157  0000  SHIMRK,   0000
0160  0000  SHMARK,   0000
0161  0000  XLMARK,   0000
0162  0000  MINC,     0000
0163  0000  SINC,     0000
0164  0545  READ,     READRT
0165  5014  ON,       JMP OTHER1
0166  5074  OFF,      JMP TTINTR
0167  0746  ADRSC6,   TABLE3+7
0170  0736  ADRSC7,   TABLE3-1
0171  0752  ADRS11,   TABLE3+13
0172  1121  TADMI4,   TAD MINUS4
0173  1124  TADMI2,   TAD MINUS2
0174  0014  DETRNR,   0014
```

```
          /TIME OF FLIGHT PROGRAM
          *200
0200  6032  BEGIN,    KCC                 /CLEAR FLAGS
0201  6042            TCF
0202  1245            TAD BELL            /RING BELL
0203  4061            JMS PRINT1
0204  1112            TAD CARRTN          /PRINT CR,LF
0205  4061            JMS PRINT1
0206  1111            TAD LNFEED
0207  4061            JMS PRINT1
0210  4564  CMMAND,   JMS I READ          /GO TO READ COMMAND
0211  1232            TAD ADRSC3          /DECODE IT
0212  3013            DCA INDEX3
0213  1234            TAD TABLE2+1
0214  3134            DCA COUNT1
0215  1246            TAD ADRSC1
0216  3130            DCA HOLD2
0217  1127            TAD HOLD1
0220  1413            TAD I INDEX3
0221  7450            SNA
0222  5227            JMP .+5
0223  2130            ISZ HOLD2
0224  2134            ISZ COUNT1
```

```
0225  5220            JMP .-5
0226  5200            JMP BEGIN          /ERROR-RESTART
0227  1530            TAD I HOLD2
0230  3130            DCA HOLD2
0231  5530            JMP I HOLD2        /GO TO PROPER ROUTINE
0232  0232  ADRSC3,    TABLE2-1
0233  7474  TABLE2,    7474               /COMMAND DECODING TABLE
0234  7766            7766
0235  7764            7764
0236  0003            0003
0237  0007            0007
0240  0013            0013
0241  7755            7755
0242  0013            0013
0243  7770            7770
0244  0011            0011
0245  0207  BELL,      0207
0246  0247  ADRSC1,    TABLE1
0247  1200  TABLE1,    DSPLAY
0250  0340            DSABLE
0251  0600            CLDATA
0252  0261            WRITE
0253  1111            PUNCH
0254  0760            EXPAND
0255  0332            ENABLE
0256  1657            LOAD
0257  1650            UPPER
0260  1641            LOWER
0261  4564  WRITE,     JMS I READ
0262  1166            TAD OFF            /DISABLE DATA TAKING
0263  3002            DCA INTER
0264  3140            DCA COUNT5
0265  1111            TAD LNFEED
0266  4070            JMS PRNTIR
0267  1153            TAD HIMARK
0270  7041            CIA
0271  1152            TAD LOMARK
0272  3141            DCA COUNT6
0273  1121            TAD MINUS4
0274  3144            DCA CONST6
0275  1167            TAD ADRSC6
0276  3145            DCA CONST7
0277  3132            DCA HIGH
0300  1234  GO1,      TAD TABLE2+1       /-10 DECIMAL
0301  3142            DCA COUNT7
0302  1150            TAD LSTORE
0303  7041            CIA
0304  1152            TAD LOMARK
0305  1140            TAD COUNT5
0306  3133            DCA LOW
0307  4777            JMS PNTDEC         /GO TO OUTPUT ROUTINE
0310  1140  GO2,      TAD COUNT5
```

```
0311  1152            TAD LOMARK
0312  3133            DCA LOW
0313  1533            TAD I LOW          /OUTPUT THIS ONE
0314  3133            DCA LOW
0315  4777            JMS PNTDEC
0316  1141            TAD COUNT6
0317  1140            TAD COUNT5         /DONE?
0320  7650            SNA CLA
0321  5776            JMP RE1            /YES
0322  2140            ISZ COUNT5         /NO
0323  2142            ISZ COUNT7         /OUTPUT 10?
0324  5310            JMP GO2            /NO
0325  1112            TAD CARRTN         /YES-TYPE CR,LF
0326  4070            JMS PRNTIR
0327  1111            TAD LNFEED
0330  4070            JMS PRNTIR
0331  5300            JMP GO1            /CONTINUE
0332  4564  ENABLE,   JMS I READ         /ENABLE DATA TAKING
0333  1111            TAD LNFEED
0334  4061            JMS PRINT1
0335  1165            TAD ON
0336  3002            DCA INTER
0337  5053            JMP CONTIN
0340  4564  DSABLE,   JMS I READ         /DISABLE DATA TAKING
0341  1111            TAD LNFEED
0342  4061            JMS PRINT1
0343  1166            TAD OFF
0344  3002            DCA INTER
0345  5053            JMP CONTIN
```

```
      /TIME OF FLIGHT PROGRAM
0376  0400  *400
0377  0661
0400  1112  RE1,       TAD CARRTN
0401  4070            JMS PRNTIR
0402  1111            TAD LNFEED
0403  4070            JMS PRNTIR
0404  5053            JMP CONTIN
0405  1166  OVRFLO,    TAD OFF            /CHANNEL OVERFLOW
0406  3002            DCA INTER          /DISABLE DATA TAKING
0407  1130            TAD HOLD2
0410  1116            TAD M2THOU
0411  3130            DCA HOLD2
0412  7240            CMA CLA
```

```
0413  1174            TAD DETRNR
0414  7640            SZA CLA
0415  5222            JMP .+5
0416  7001            IAC
0417  3140            DCA COUNT5
0420  1130            TAD HOLD2
0421  5247            JMP .+26
0422  3133            DCA LOW
0423  1174            TAD DETRNR
0424  7110            CLL RAR
0425  2133            ISZ LOW
0426  7440            SZA
0427  5224            JMP .-3
0430  1377            TAD (-14)
0431  1133            TAD LOW
0432  3133            DCA LOW
0433  1133            TAD LOW
0434  3132            DCA HIGH
0435  1130            TAD HOLD2
0436  7110            CLL RAR
0437  2132            ISZ HIGH
0440  5236            JMP .-2
0441  7001            IAC
0442  3140            DCA COUNT5
0443  7124            STL RAL
0444  2133            ISZ LOW
0445  5243            JMP .-2
0446  0130            AND HOLD2
0447  3131            DCA HOLD3
0450  1131  CASEX,     TAD HOLD3
0451  3133            DCA LOW
0452  3132            DCA HIGH
0453  1121            TAD MINUS4
0454  3144            DCA CONST6
0455  1167            TAD ADRSC6
0456  3145            DCA CONST7
0457  4776            JMS PNTDEC
0460  1140            TAD COUNT5
0461  3133            DCA LOW
0462  3132            DCA HIGH
0463  1124            TAD MINUS2
0464  3144            DCA CONST6
0465  1171            TAD ADRS11
0466  3145            DCA CONST7
0467  4776            JMS PNTDEC
0470  5323            JMP PRFULL
0471  0000  INPUT4,    0                    /INPUT 4 DECIMALS
0472  1121            TAD MINUS4
0473  3134            DCA COUNT1
0474  3147            DCA PRODCT
0475  4564            JMS I READ
0476  1127            TAD HOLD1
```

```
0477  0126             AND MASK15
0500  1147             TAD PRODCT
0501  2134             ISZ COUNT1
0502  7410             SKP
0503  5671             JMP I INPUT4
0504  7104             CLL RAL
0505  3147             DCA PRODCT
0506  1147             TAD PRODCT
0507  7006             RTL
0510  1147             TAD PRODCT
0511  3147             DCA PRODCT
0512  5275             JMP INPUT4+4
0513  0000  INPUT2,     0                    'INPUT 2 DECIMALS
0514  1173             TAD TADMI2
0515  3272             DCA INPUT4+1         /MODIFY FOR 2 DECIMALS
0516  4271             JMS INPUT4
0517  3147             DCA PRODCT
0520  1172             TAD TADMI4           /RESTORE INPUT4
0521  3272             DCA INPUT4+1
0522  5713             JMP I INPUT2
0523  1344  PRFULL,     TAD ADRSC4           /PRINT ''FULL,CR,LF''
0524  3012             DCA INDEX2
0525  1412             TAD I INDEX2
0526  7450             SNA
0527  5332             JMP .+3
0530  4070             JMS PRNTIR
0531  5325             JMP .-4
0532  1165             TAD ON
0533  3002             DCA INTER
0534  5053             JMP CONTIN
0535  0306  TABLE6,     0306
0536  0325             0325
0537  0314             0314
0540  0314             0314
0541  0215             0215
0542  0212             0212
0543  0000             0000
0544  0534  ADRSC4,     TABLE6-1
0545  0000  READRT,     0000                 /READ ROUTINE
0546  7200             CLA
0547  6031             KSF
0550  5347             JMP .-1
0551  6036             KRB
0552  3127             DCA HOLD1
0553  1127             TAD HOLD1
0554  4061             JMS PRINT1
0555  1127             TAD HOLD1
0556  1115             TAD MRBOUT           /RUBOUT?
0557  7650             SNA CLA
0560  5362             JMP IPCORR           /YES
0561  5745             JMP I READRT
0562  1172  IPCORR,     TAD TADMI4
0563  3272             DCA INPUT4+1
0564  5775             JMP BEGIN
```

```
                /TIME OF FLIGHT PROGRAM
0575  0200      *600
0576  0661
0577  7764
0600  4564  CLDATA,    JMS I READ              /CLEAR DATA ROUTINE
0601  1166              TAD OFF                 /DISABLE DATA TAKING
0602  3002              DCA INTER
0603  1114              TAD MINCR
0604  1127              TAD HOLD1
0605  7640              SZA CLA                 /IS IT CR?
0606  5214              JMP .+6                 /NO-GO TO INPUT 2 DECIMALS
0607  7040              CMA
0610  3154              DCA WHMARK
0611  1120              TAD P2THOU
0612  3151              DCA WLMARK
0613  5217              JMP .+4
0614  4777              JMS INPUT2
0615  4776              JMS WMARK
0616  4564              JMS I READ
0617  1151              TAD WLMARK
0620  1123              TAD MINUS1
0621  3011              DCA INDEX1
0622  1154              TAD WHMARK
0623  7040              CMA
0624  1151              TAD WLMARK
0625  3134              DCA COUNT1
0626  3411              DCA I INDEX1
0627  2134              ISZ COUNT1
0630  5226              JMP .-2
0631  5775              JMP RE1
0632  0000  SHIFTL,     0                       /SHIFT LEFT ROUTINE
0633  7450              SNA
0634  5254              JMP SHFTRG-2
0635  7500              SMA
0636  5243              JMP .+5
0637  3255              DCA SHFTRG-1
0640  1257              TAD SHFTRG+1
0641  3250              DCA .+7
0642  5247              JMP .+5
0643  7041              CMA IAC
0644  3255              DCA SHFTRG-1
0645  1260              TAD SHFTRG+2
0646  3250              DCA .+2
0647  1256              TAD SHFTRG
0650  0000              0
0651  2255              ISZ SHFTRG-1
0652  5250              JMP .-2
0653  3256              DCA SHFTRG
0654  5632              JMP I SHIFTL
0655  0000              0
0656  0000  SHFTRG,     0
0657  7110              CLL RAR
```

```
0660  7104            CLL RAL
0661  0000  PNTDEC,    0                        /PRINT DECIMAL
0662  1144            TAD CONST6
0663  3143            DCA COUNT8
0664  1145            TAD CONST7
0665  3012            DCA INDEX2
0666  1412            TAD I INDEX2
0667  3333            DCA HSUB
0670  1412            TAD I INDEX2
0671  3334            DCA LSUB
0672  3336            DCA CHRCTR
0673  4312            JMS ADD
0674  1336            TAD CHRCTR
0675  1357            TAD ZERO
0676  4070            JMS PRNTIR
0677  2143            ISZ COUNT8
0700  5266            JMP .-12
0701  1121            TAD MINUS4
0702  7001            IAC
0703  3143            DCA COUNT8
0704  2143            ISZ COUNT8
0705  7410            SKP
0706  5661            JMP I PNTDEC
0707  1110            TAD SPACE
0710  4070            JMS PRNTIR
0711  5304            JMP .-5
0712  0000  ADD,       0
0713  7100            CLL
0714  1133            TAD LOW
0715  1334            TAD LSUB
0716  3335            DCA TEMPL
0717  7004            RAL
0720  1132            TAD HIGH
0721  1333            TAD HSUB
0722  7420            SNL
0723  5331            JMP .+6
0724  3132            DCA HIGH
0725  1335            TAD TEMPL
0726  3133            DCA LOW
0727  2336            ISZ CHRCTR
0730  5313            JMP ADD+1
0731  7200            CLA
0732  5712            JMP I ADD
0733  0000  HSUB,      0
0734  0000  LSUB,      0
0735  0000  TEMPL,     0
0736  0000  CHRCTR,    0
0737  3166  TABLE3,    3166
0740  4600            4600
0741  7413            7413
0742  6700            6700
0743  7747            7747
```

```
0744  4540                4540
0745  7775                7775
0746  4360                4360
0747  7777                7777
0750  6030                6030
0751  7777                7777
0752  7634                7634
0753  7777                7777
0754  7766                7766
0755  7777                7777
0756  7777                7777
0757  0260  ZERO,         0260
0760  4564  EXPAND,       JMS I READ
0761  1111                TAD LNFEED
0762  4061                JMS PRINT1
0763  1152                TAD LOMARK
0764  3151                DCA WLMARK
0765  1153                TAD HIMARK
0766  3154                DCA WHMARK
0767  5774                JMP GO3+6
```

```
      /TIME OF FLIGHT PROGRAM
0774  1311  *1000
0775  0400
0776  1000
0777  0513
1000  0000  WMARK,        0                    /PRODUCES FROM DETRNR AND
1001  1227                TAD ADRSC9           /PRODCT (WHICH CONTAINS
1002  3131                DCA HOLD3            /A DETECTOR NUMBER) THE REAL
1003  1222                TAD ADRSC8           /MEMORY ADDRESS OF FIRST
1004  3013                DCA INDEX3           /AND LAST CHANNEL CORRESPON
1005  1121                TAD MINUS4           /TO THAT DETECTOR
1006  3134                DCA COUNT1
1007  1174                TAD DETRNR
1010  1413                TAD I INDEX3
1011  7450                SNA
1012  5217                JMP .+5
1013  2131                ISZ HOLD3
1014  2134                ISZ COUNT1
1015  5210                JMP .-5
1016  5777                JMP BEGIN            /ILLEGAL DETRNR,COMMAND IS
1017  1531                TAD I HOLD3
1020  3131                DCA HOLD3
1021  5531                JMP I HOLD3          /GO TO CASE OR CAS
```

```
1022  1022  ADRSC8,   TABLE4-1
1023  7764  TABLE4,   7764
1024  0006            0006
1025  0003            0003
1026  0002            0002
1027  1030  ADRSC9,   TABLE5
1030  1034  TABLE5,   CASE12
1031  1051            CASE6
1032  1066            CASE3
1033  1103            CASE1
1034  7040  CASE12,   CMA
1035  1147            TAD PRODCT
1036  7100            CLL
1037  7012            RTR
1040  7012            RTR
1041  7010            RAR
1042  1120            TAD P2THOU
1043  3151            DCA WLMARK
1044  1151            TAD WLMARK
1045  1122            TAD P4HUN
1046  1123            TAD MINUS1
1047  3154            DCA WHMARK
1050  5600            JMP I WMARK
1051  7040  CASE6,    CMA
1052  1147            TAD PRODCT
1053  7100            CLL
1054  7012            RTR
1055  7012            RTR
1056  1120            TAD P2THOU
1057  3151            DCA WLMARK
1060  1122            TAD P4HUN
1061  7004            RAL
1062  1151            TAD WLMARK
1063  1123            TAD MINUS1
1064  3154            DCA WHMARK
1065  5600            JMP I WMARK
1066  7040  CASE3,    CMA
1067  1147            TAD PRODCT
1070  7100            CLL
1071  7012            RTR
1072  7010            RAR
1073  1120            TAD P2THOU
1074  3151            DCA WLMARK
1075  1122            TAD P4HUN
1076  7006            RTL
1077  1151            TAD WLMARK
1100  1123            TAD MINUS1
1101  3154            DCA WHMARK
1102  5600            JMP I WMARK
1103  1120  CASE1,    TAD P2THOU
1104  3151            DCA WLMARK
1105  1151            TAD WLMARK
```

```
1106  1125          TAD MSIZE
1107  3154          DCA WHMARK
1110  5600          JMP I WMARK
1111  4564  PUNCH,  JMS I READ
1112  1166          TAD OFF
1113  3002          DCA INTER
1114  1111          TAD LNFEED
1115  4070          JMS PRNTIR
1116  4776          JMS LEADIN
1117  1152          TAD LOMARK
1120  3140          DCA COUNT5
1121  1153          TAD HIMARK
1122  7041          CIA
1123  3141          DCA COUNT6
1124  3133          DCA LOW
1125  1140          TAD COUNT5
1126  7120          STL
1127  4775          JMS BINPCH
1130  1540          TAD I COUNT5
1131  7100          CLL
1132  4775          JMS BINPCH
1133  1140          TAD COUNT5
1134  1141          TAD COUNT6
1135  7650          SNA CLA
1136  5341          JMP .+3
1137  2140          ISZ COUNT5
1140  5330          JMP .-10
1141  7100          CLL
1142  1133          TAD LOW
1143  4775          JMS BINPCH
1144  4776          JMS LEADIN
1145  5053          JMP CONTIN
1146  0000  SCALE,  0                    /SET UP SCALE MARKERS
1147  7101          CLL IAC
1150  7006          RTL
1151  6067          DYS
1152  7006          RTL
1153  6067          DYS
1154  7200          CLA
1155  5746          JMP I SCALE
1156  0000  MARK,   0                    /DRAW VERTICAL LINE
1157  1120          TAD P2THOU
1160  7100          CLL
1161  1107          TAD MIN20
1162  7430          SZL
1163  5366          JMP .+3
1164  7200          CLA
1165  5756          JMP I MARK
1166  6067          DYS
1167  5360          JMP .-7
```

```
                /TIME OF FLIGHT PROGRAM
1175  1600      *1200
1176  1627
1177  0200
1200  4564  DSPLAY,    JMS I READ          /READ NEXT CHARACTER
1201  3777              DCA SCALEL
1202  3776              DCA SCALEU
1203  1127              TAD HOLD1
1204  1114              TAD MINCR
1205  7640              SZA CLA             /IS IT CR?
1206  5220              JMP .+12            /NO
1207  1120              TAD P2THOU          /YES-SET LOMARK=2000
1210  3152              DCA LOMARK          /AND HIMARK=7777
1211  1152              TAD LOMARK
1212  3151              DCA WLMARK
1213  7040              CMA
1214  3153              DCA HIMARK
1215  1153              TAD HIMARK
1216  3154              DCA WHMARK
1217  5303              JMP GO3
1220  4775              JMS INPUT2          /INPUT 2 DECIMALS
1221  4774              JMS WMARK           /PRODUCE WHMARK,WLMARK
1222  4564              JMS I READ          /READ NEXT CHARACTER
1223  1127              TAD HOLD1
1224  1114              TAD MINCR
1225  7640              SZA CLA             /IS IT CR?
1226  5234              JMP .+6             /NO
1227  1151              TAD WLMARK          /YES-SET LOMARK=WLMARK
1230  3152              DCA LOMARK          /AND HIMARK=WHMARK
1231  1154              TAD WHMARK
1232  3153              DCA HIMARK
1233  5303              JMP GO3
1234  4773              JMS INPUT4          /INPUT 4 DECIMALS
1235  1151              TAD WLMARK          /SET LOMARK=WLMARK+
1236  3152              DCA LOMARK          /READ-IN VALUE
1237  4564              JMS I READ          /READ NEXT CHARACTER
1240  1127              TAD HOLD1
1241  1114              TAD MINCR
1242  7640              SZA CLA             /IS IT CR?
1243  5247              JMP .+4             /NO
1244  1154              TAD WHMARK          /YES-SET HIMARK=WHMARK
1245  3153              DCA HIMARK
1246  5303              JMP GO3
1247  4773              JMS INPUT4          /INPUT 4 DECIMALS
1250  1151              TAD WLMARK          /SET HIMARK=WLMARK+
1251  3153              DCA HIMARK          /READ-IN VALUE
1252  4564              JMS I READ          /READ NEXT CHARACTER
1253  1127              TAD HOLD1
1254  1114              TAD MINCR
1255  7650              SNA CLA             /IS IT CR?
1256  5303              JMP GO3             /YES
1257  4775              JMS INPUT2          /NO-INPUT 2 DECIMALS
```

```
1260  1151          TAD WLMARK
1261  3136          DCA COUNT3
1262  1154          TAD WHMARK
1263  3135          DCA COUNT2
1264  4774          JMS WMARK          /PRODUCE XLMARK
1265  1151          TAD WLMARK
1266  3161          DCA XLMARK
1267  1136          TAD COUNT3
1270  3151          DCA WLMARK
1271  1135          TAD COUNT2
1272  3154          DCA WHMARK
1273  1151          TAD WLMARK
1274  7041          CIA
1275  1161          TAD XLMARK
1276  3772          DCA MDIFF
1277  1771          TAD MDIFF+2        /SWITCH FOR MULTIPLE
1300  3770          DCA SWITCH         /DISPLAY
1301  4564          JMS I READ         /READ NEXT CHARACTER
1302  5305          JMP .+3
1303  1767  GO3,    TAD MDIFF+1        /SWITCH FOR SINGLE
1304  3770          DCA SWITCH         /DISPLAY
1305  1111          TAD LNFEED
1306  4061          JMS PRINT1
1307  1151          TAD WLMARK
1310  3150          DCA LSTORE
1311  1151          TAD WLMARK         /CALCULATE SCREEN MARKERS
1312  7041          CIA
1313  1154          TAD WHMARK
1314  3360          DCA WHL
1315  3361          DCA NRS
1316  1360          TAD WHL
1317  7510          SPA
1320  5324          JMP .+4
1321  7124          STL RAL
1322  2361          ISZ NRS
1323  5317          JMP .-4
1324  7200          CLA
1325  1361          TAD NRS
1326  1124          TAD MINUS2
1327  3361          DCA NRS
1330  1361          TAD NRS
1331  7710          SPA CLA
1332  5344          JMP .+12
1333  7001          IAC
1334  3162          DCA MINC
1335  7001          IAC
1336  3766          DCA SHFTRG
1337  1361          TAD NRS
1340  4765          JMS SHIFTL
1341  1766          TAD SHFTRG
1342  3163          DCA SINC
1343  5355          JMP .+12
```

```
1344   7001            IAC
1345   3163            DCA SINC
1346   7001            IAC
1347   3766            DCA SHFTRG
1350   1361            TAD NRS
1351   7041            CIA
1352   4765            JMS SHIFTL
1353   1766            TAD SHFTRG
1354   3162            DCA MINC
1355   1360            TAD WHL
1356   3766            DCA SHFTRG
1357   5764            JMP 1400
1360   0000  WHL,       0
1361   0000  NRS,       0
```

```
                /TIME OF FLIGHT PROGRAM
1364   1400  *1400
1365   0632
1366   0656
1367   1542
1370   1507
1371   1543
1372   1541
1373   0471
1374   1000
1375   0513
1376   1656
1377   1655
1400   1777            TAD NRS
1401   4776            JMS SHIFTL
1402   1775            TAD SHFTRG
1403   3774            DCA WHL
1404   1774            TAD WHL
1405   7110            CLL RAR
1406   7040            CMA
1407   1117            TAD P1THOU
1410   3155            DCA SLMARK
1411   1155            TAD SLMARK
1412   1774            TAD WHL
1413   3160            DCA SHMARK
1414   1151            TAD WLMARK
1415   7041            CIA
1416   1152            TAD LOMARK
1417   3775            DCA SHFTRG
```

```
1420  1777            TAD NRS
1421  4776            JMS SHIFTL
1422  1775            TAD SHFTRG
1423  1155            TAD SLMARK
1424  3156            DCA SLOMRK
1425  1151            TAD WLMARK
1426  7041            CIA
1427  1153            TAD HIMARK
1430  3775            DCA SHFTRG
1431  1777            TAD NRS
1432  4776            JMS SHIFTL
1433  1775            TAD SHFTRG
1434  1155            TAD SLMARK
1435  3157            DCA SHIMRK
1436  6001            ION
1437  1155  INDSPL,   TAD SLMARK        /INITIALIZE DISPLAY COUNTERS
1440  3134            DCA COUNT1
1441  1134            TAD COUNT1
1442  3135            DCA COUNT2
1443  1151            TAD WLMARK
1444  3136            DCA COUNT3
1445  1134            TAD COUNT1        /NEW VALUE IN XBUFFER
1446  6053            DXL
1447  7200            CLA               /ZERO IN YBUFFER
1450  6067            DYS               /DISPLAY IT
1451  1155            TAD SLMARK        /IS SCALE MARKER REQUIRED?
1452  7041            CIA
1453  1134            TAD COUNT1
1454  0345            AND MASKX
1455  7041            CIA
1456  1345            TAD MASKX
1457  7650            SNA CLA
1460  4773            JMS SCALE         /YES-DISPLAY SCALE MARKER
1461  1134            TAD COUNT1
1462  7041            CIA
1463  1135            TAD COUNT2
1464  7640            SZA CLA
1465  5331            JMP GO4           /NO
1466  1134            TAD COUNT1        /YES-IS VERT.LINE REQUIRED?
1467  7041            CIA
1470  1156            TAD SLOMRK
1471  7650            SNA CLA
1472  4772            JMS MARK          /YES-DRAW VERT.LINE
1473  1134            TAD COUNT1        /NO-IS VERT.LINE REQUIRED?
1474  7041            CIA
1475  1157            TAD SHIMRK
1476  7650            SNA CLA
1477  4772            JMS MARK          /YES-DRAW VERT.LINE
1500  1536            TAD I COUNT3      /NO-SCALE FUNCTION
1501  3775            DCA SHFTRG
1502  1771            TAD SCALEL
1503  1124            TAD MINUS2
```

```
1504  4776            JMS SHIFTL
1505  1775            TAD SHFTRG
1506  6067            DYS                 /DISPLAY FUNCTION
1507  0000  SWITCH,    0                   /SWITCH FOR SINGLE/MULTIPLE
1510  1136            TAD COUNT3          /TAKE 2ND FUNCTION VALUE
1511  1341            TAD MDIFF           /SCALE AND DISPLAY IT
1512  3344            DCA TEMP
1513  1744            TAD I TEMP
1514  3775            DCA SHFTRG
1515  1770            TAD SCALEU
1516  1124            TAD MINUS2
1517  4776            JMS SHIFTL
1520  1775            TAD SHFTRG
1521  6067            DYS
1522  7200            CLA
1523  1136            TAD COUNT3
1524  1162            TAD MINC
1525  3136            DCA COUNT3
1526  1135            TAD COUNT2
1527  1163            TAD SINC
1530  3135            DCA COUNT2
1531  2134  GO4,      ISZ COUNT1
1532  1134            TAD COUNT1
1533  7041            CIA
1534  7001            IAC
1535  1160            TAD SHMARK
1536  7650            SNA CLA
1537  5237            JMP INDSPL
1540  5245            JMP INDSPL+6
1541  0000  MDIFF,     0
1542  5322            JMP SWITCH+13
1543  7200            CLA
1544  0000  TEMP,      0
1545  0077  MASKX,     0077
```

```
      /TIME OF FLIGHT PROGRAM
1570  1656  *1600
1571  1655
1572  1156
1573  1146
1574  1360
1575  0656
1576  0632
1577  1361
```

```
1600  0000  BINPCH,   0
1601  3143            DCA COUNT8
1602  1143            TAD COUNT8
1603  7012            RTR
1604  7012            RTR
1605  7012            RTR
1606  0217            AND MASK7
1607  4220            JMS CHECK
1610  4070            JMS PRNTIR
1611  1143            TAD COUNT8
1612  0216            AND MASK6
1613  4220            JMS CHECK
1614  4070            JMS PRNTIR
1615  5600            JMP I BINPCH
1616  0077  MASK6,    0077
1617  0177  MASK7,    0177
1620  0000  CHECK,    0
1621  3142            DCA COUNT7
1622  1142            TAD COUNT7
1623  1133            TAD LOW
1624  3133            DCA LOW
1625  1142            TAD COUNT7
1626  5620            JMP I CHECK
1627  0000  LEADIN,   0
1630  1240            TAD COD200
1631  7041            CMA IAC
1632  3141            DCA COUNT6
1633  1240            TAD COD200
1634  4070            JMS PRNTIR
1635  2141            ISZ COUNT6
1636  5233            JMP .-3
1637  5627            JMP I LEADIN
1640  0200  COD200,   0200
1641  4564  LOWER,    JMS I READ          /CHANGE SENSITIVITY OF
1642  1127            TAD HOLD1           /DISPLAY FOR DETECTOR IN
1643  0126            AND MASK15          /LOWER POSITION
1644  3255            DCA SCALEL
1645  1110            TAD SPACE
1646  4061            JMS PRINT1
1647  5053            JMP CONTIN
1650  4564  UPPER,    JMS I READ          /CHANGE SENSITIVITY OF
1651  1127            TAD HOLD1           /DISPLAY FOR DETECTOR IN
1652  0126            AND MASK15          /UPPER POSITION
1653  3256            DCA SCALEU
1654  5245            JMP LOWER+4
1655  0000  SCALEL,   0
1656  0000  SCALEU,   0
1657  4564  LOAD,     JMS I READ
1660  1111            TAD LNFEED
1661  4061            JMS PRINT1
1662  1166            TAD OFF
1663  3002            DCA INTER
```

```
1664  3133              DCA LOW
1665  4356              JMS BINRD
1666  1367              TAD MIN200
1667  7650              SNA CLA
1670  5265              JMP .-3
1671  1127              TAD HOLD1
1672  4220              JMS CHECK
1673  7106              CLL RTL
1674  7006              RTL
1675  7006              RTL
1676  3143              DCA COUNT8
1677  4356              JMS BINRD
1700  4220              JMS CHECK
1701  1143              TAD COUNT8
1702  3143              DCA COUNT8
1703  1143              TAD COUNT8
1704  3366              DCA ADDRES
1705  4356  RETURN,     JMS BINRD
1706  1367              TAD MIN200
1707  7650              SNA CLA
1710  5340              JMP HALT
1711  1127              TAD HOLD1
1712  4220              JMS CHECK
1713  3370              DCA RDSTR1
1714  1370              TAD RDSTR1
1715  7106              CLL RTL
1716  7006              RTL
1717  7006              RTL
1720  3143              DCA COUNT8
1721  4356              JMS BINRD
1722  4220              JMS CHECK
1723  3371              DCA RDSTR2
1724  1371              TAD RDSTR2
1725  1143              TAD COUNT8
1726  3143              DCA COUNT8
1727  7100              CLL
1730  1143              TAD COUNT8
1731  1766              TAD I ADDRES
1732  7430              SZL
1733  7240              CMA CLA
1734  3766              DCA I ADDRES
1735  2366              ISZ ADDRES
1736  7000              NOP
1737  5305              JMP RETURN
1740  7040  HALT,       CMA
1741  1366              TAD ADDRES
1742  3366              DCA ADDRES
1743  1143              TAD COUNT8
1744  7041              CIA
1745  1766              TAD I ADDRES
1746  3766              DCA I ADDRES
1747  1133              TAD LOW
```

```
1750  7041            CIA
1751  1370            TAD RDSTR1
1752  1371            TAD RDSTR2
1753  1143            TAD COUNT8
1754  7402            HLT
1755  5777            JMP RE1
1756  0000  BINRD,     0000
1757  7200            CLA
1760  6031            KSF
1761  5360            JMP .-1
1762  6036            KRB
1763  3127            DCA HOLD1
1764  1127            TAD HOLD1
1765  5756            JMP I BINRD
1766  0000  ADDRES,    0000
1767  7600  MIN200,    7600
1770  0000  RDSTR1,    0000
1771  0000  RDSTR2,    0000
1777  0400  $
```

```
/TIME-OF-FLIGHT-COMMANDS
TFS=6401              /SKIP IF TOF FLAG IS SET
TFL=6406              /READ TOF AND RESET
TFC=6404              /CLEAR TOF FLAG
```

AC	0007	HOLD3	0131	P4RUN	0122
ADD	0712	HSUB	0733	QMARK	0113
ADDRES	1766	INDEX1	0011	RDSTR1	1770
ADRSC1	0246	INDEX2	0012	RDSTR2	1771
ADRSC3	0232	INDEX3	0013	READ	0164
ADRSC4	0544	INDSPL	1437	READRT	0545
ADRSC6	0167	INPUT2	0513	RESTRT	0041
ADRSC7	0170	INPUT4	0471	RESUME	0042
ADRSC8	1022	INTER	0002	RETURN	1705
ADRSC9	1027	IPCORR	0562	RE1	0400
ADRS11	0171	LEADIN	1627	SAVEAC	0004
BEGIN	0200	LINK	0010	SAVEL	0005
BELL	0245	LNFEED	0111	SCALE	1146
BINPCH	1600	LOAD	1657	SCALEL	1655
BINRD	1756	LOMARK	0152	SCALEU	1656
CARRTN	0112	LOW	0133	SHFTRG	0656
CASEX	0450	LOWER	1641	SHIFTL	0632
CASE1	1103	LOWPWR	0031	SHIMRK	0157
CASE12	1034	LSTORE	0150	SHMARK	0160
CASE3	1066	LSUB	0734	SINC	0163
CASE6	1051	MARK	1156	SLMARK	0155
CHECK	1620	MASKX	1545	SLOMRK	0156
CHRCTR	0736	MASK15	0126	SPACE	0110
CLDATA	0600	MASK6	1616	SWITCH	1507
CMMAND	0210	MASK7	1617	TABLE1	0247
COD200	1640	MDIFF	1541	TABLE2	0233
CONST6	0144	MINC	0162	TABLE3	0737
CONST7	0145	MINCR	0114	TABLE4	1023
CONST8	0146	MINUS1	0123	TABLE5	1030
CONTIN	0053	MINUS2	0124	TABLE6	0535
COUNT1	0134	MINUS4	0121	TADMI2	0173
COUNT2	0135	MIN20	0107	TADMI4	0172
COUNT3	0136	MIN200	1767	TEMP	1544
COUNT4	0137	MRBOUT	0115	TEMPL	0735
COUNT5	0140	MSIZE	0125	TTINTR	0074
COUNT6	0141	M2THOU	0116	UPPER	1650
COUNT7	0142	NRS	1361	WHL	1360
COUNT8	0143	OFF	0166	WHMARK	0154
DETRNR	0174	ON	0165	WLMARK	0151
DSABLE	0340	OTHER1	0014	WMARK	1000
DSPLAY	1200	OTHER2	0047	WRITE	0261
ENABLE	0332	OTHER3	0104	XLMARK	0161
EXPAND	0760	OVRFLO	0405	ZERO	0757
GO1	0300	PC	0006		
GO2	0310	PNTDEC	0661		
GO3	1303	PRFULL	0523		
GO4	1531	PRINT1	0061		
HALT	1740	PRNTIR	0070		
HIGH	0132	PRODCT	0147		
HIMARK	0153	PUNCH	1111		
HOLD1	0127	P1THOU	0117		
HOLD2	0130	P2THOU	0120		

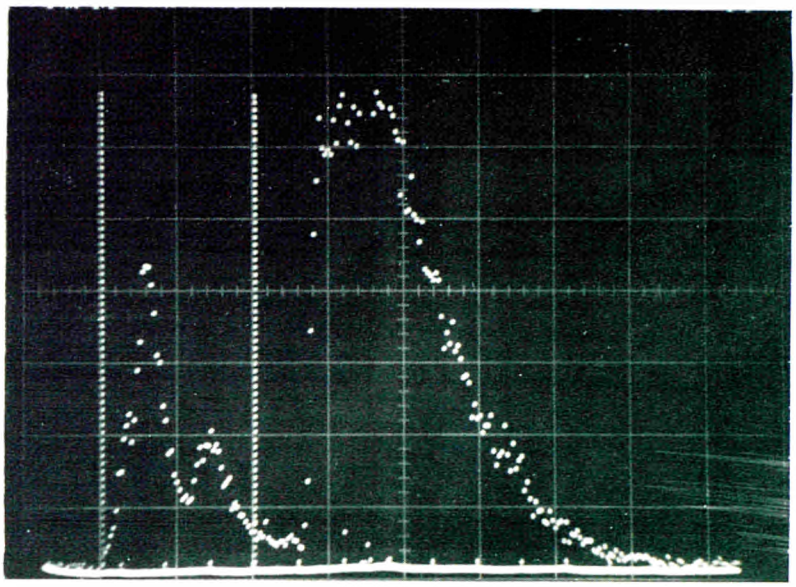


Fig.1
Sample spectrum (see p.19)

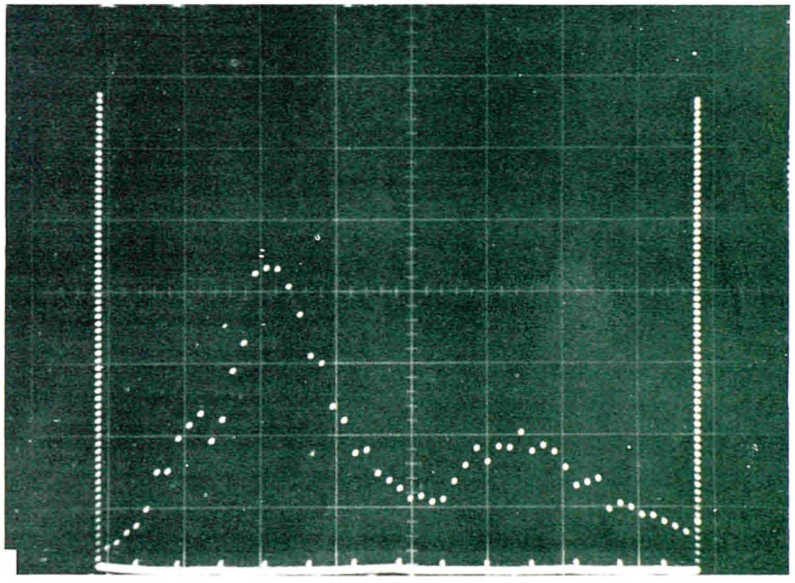


Fig.2
Expanded view of sample spectrum

Block Nr	Memory locations		Block Nr	Memory locations	
	from	to		from	to
0	2000	2377	6	5000	5377
1	2400	2777	7	5400	5777
2	3000	3377	8	6000	6377
3	3400	3777	9	6400	6777
4	4000	4377	10	7000	7377
5	4400	4777	11	7400	7777

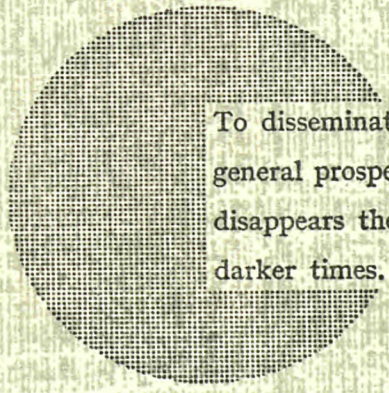
Table 1

Memory location table

0000	0000	0002	0004	0007	0005	0004	0004	0002	0008	0007
0010	0002	0004	0007	0001	0008	0002	0004	0003	0009	0002
0020	0002	0006	0001	0001	0005	0008	0021	0027	0038	0046
0030	0064	0103	0104	0139	0153	0165	0136	0159	0211	0241
0040	0317	0323	0322	0303	0272	0227	0219	0173	0158	0123
0050	0126	0101	0093	0085	0075	0078	0072	0075	0094	0111
0060	0129	0115	0131	0130	0146	0126	0132	0125	0108	0089
0070	0093	0097	0065	0071	0067	0059	0058	0052	0047	0041
0080	0050	0033	0039	0035	0051	0034	0030	0028	0026	0030
0090	0030	0026	0033	0036	0031	0030	0024	0023	0047	0093
0100	0253	0358	0415	0482	0450	0443	0448	0443	0480	0455
0110	0495	0507	0550	0477	0456	0494	0452	0487	0517	0517
0120	0536	0520	0487	0510	0498	0494	0514	0518	0493	0485
0130	0468	0459	0400	0457	0382	0384	0420	0379	0374	0350
0140	0372	0321	0317	0314	0309	0317	0309	0269	0234	0251
0150	0239	0263	0231	0237	0223	0203	0205	0197	0160	0174
0160	0159	0162	0144	0152	0152	0163	0125	0110	0120	0124
0170	0152	0121	0104	0133	0106	0115	0119	0083	0092	0074
0180	0056	0071	0061	0062	0050	0048	0061	0051	0043	0048
0190	0050	0029	0049	0028	0037	0036	0041	0034	0027	0031
0200	0031	0031	0021	0019	0023	0016	0025	0013	0017	0015
0210	0021	0011	0017	0011	0013	0014	0016	0012	0015	0015
0220	0013	0015	0012	0008	0011	0007	0009	0008	0005	0015
0230	0007	0006	0005	0011	0010	0003	0005	0004	0005	0007
0240	0009	0011	0006	0007	0003	0004	0008	0009	0013	0007
0250	0007	0006	0004	0007	0008	0008				

Table 2

Print-out for sample run



To disseminate knowledge is to disseminate prosperity — I mean general prosperity and not individual riches — and with prosperity disappears the greater part of the evil which is our heritage from darker times.

Alfred Nobel

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